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Geiger-Mueller counters for low energy electrons

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Abstract

It has been found that the most extensive and most accurate work in beta-ray spectroscopy can be performed only when reliable, low energy sensitive, beta-particle detectors are employed. One method of obtaining low energy electron measurements is to fit Geiger-Mueller counters with extremely thin windows and to fill them with appropriate low-pressure mixtures, using them in spectrometers in much the same manner as their more rugged counterparts. A plan for an experimental assault on the problem, based upon the works of Wilkinson, Bamsaur, McKay and Loeb is presented.

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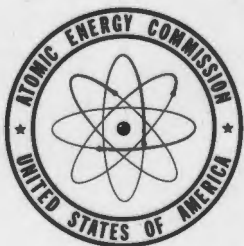
By

E. R. Rathbun, Jr.

E. N. Jensen

August 1950

Ames Laboratory



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GEIGER-MUELLER COUNTERS FOR LOW ENERGY ELECTRONS¹

Edwin R. Rathbun, Jr.

E. N. Jensen

ABSTRACT

It has been found that the most extensive and most accurate work in beta-ray spectroscopy can be performed only when reliable, low-energy sensitive, beta-particle detectors are employed. One method of obtaining low energy electron measurements is to fit Geiger-Mueller counters with extremely thin windows and to fill them with appropriate low-pressure mixtures, using them in spectrometers in much the same manner as their more rugged counterparts. A plan for an experimental assault on the problem, based upon the works of Wilkinson, Ramsaur, McKay, and Loeb is presented.

Procedures for the preparation of thin film window materials by the glass plate dipping technique and the drop of solution technique are described. A method for mounting these window materials in counters is given. Complete recipes of each step necessary to produce in a reliable manner dependable counters are described. These include the preparation and cleaning of the parts prior to assembly, the preparation of vacuum tight joints, assembling the parts, testing the window for vacuum tightness, filling the counter, testing the counter and storing it prior to use.

Apparatus and procedures employed in the development of mixtures which will function at low pressures in Geiger-Mueller counters are explained. Illustrations show much of what was done. Special electronic techniques, distinctive in that the performance of the counter was enhanced by elaborate electronic design, were used. It was found that low Geiger-Mueller counter anode capacitance to ground was vital to success. The cathode follower circuit was a prominent part of the equipment throughout the work. An additional feature of the apparatus was a synchroscope, used frequently to view the size and shape of the pulses produced by the counter tubes, both during the development of them and during their use.

A number of different mixtures of gases and vapors were found that are of value in counters used in beta-ray spectroscopy. These included the classic one of 10 percent ethyl alcohol and 90 percent argon at a pressure of 10 cm Hg, one developed by Morganstern, Cowan, and Hughes which consisted of 10 percent ethylene and 90 percent argon at 10 cm Hg, and those which were derived from this study. The latter group included a mixture of 33 percent ethyl alcohol and 67 percent argon at a pressure of 1.4 cm Hg and a second

¹This report is based on a MS thesis by E. R. Rathbun, Jr., submitted August, 1950.

one consisting of 40 percent ethyl alcohol and 60 percent krypton at pressures of 2 cm and 1.4 cm Hg. The somewhat higher efficiency of the krypton mixtures made them the more desirable at the lowest pressures. Geiger-Mueller counters have more stable counting characteristics as their efficiencies approach 100 percent.

Data on the internal conversion and photoelectric spectra of Se^{75} were taken using four different counters, each constructed by the above indicated techniques. They were fitted with windows as follows: 3.9 mg/cm² mica, 1.04 mg/cm² mica, 0.3 mg/cm² formvar, and 0.027 mg/cm² formvar. Electrons were completely absorbed in these windows for all energies below 44 Kev, 23.2 Kev, 13.7 Kev, and 4.3 Kev respectively. Using the thinnest window in a counter, internal conversion lines were found at 9.07 Kev and 10.31 Kev. These lines result from the X-ray energy of arsenic less respectively the L- and M-binding energies. If the L-binding energy for arsenic is 1.52 Kev, then the X-ray energy for arsenic is 10.59 Kev, in good agreement with Compton and Allison's value of 10.54 Kev.

INTRODUCTION

The Problem

It has been found, in the work of beta-ray spectroscopy, that one of the limitations on the determination of low energy beta-ray spectra is the thickness (or area density) of the Geiger-Mueller counter window. In the work of Jensen, Laslett, and Pratt (1-4) and others (5,6), the effect of the counter window has been well demonstrated. It is therefore necessary, if the precision of the magnetic lens spectrometer is to be had, that a counter be developed which has a window sufficiently thin to allow the electrons to enter its counting volume and, at the same time, maintain the counting efficiency at a useful and stable level. The experimental procedures and techniques whereby such counters can be obtained is the subject of this investigation.

General Discussion

There are certain practical and theoretical considerations which must be taken into account in the development of a counter which has a thin window and at the same time has other useful and desirable characteristics. Once an electron has passed through the thin window, it must ionize some of the atoms or molecules of

gas or vapor within the counter before a voltage pulse of sufficient size to be detected can be produced. This primary ionization process is accomplished through the first Townsend coefficient a_1 for the incoming particle in the particular counter filler employed. This first Townsend coefficient a_1 tells one what the probability of additional ions being formed per centimeter of path is within the counter. After these additional ions are formed, the electrons migrate rapidly in the direction of the anode. Since these electrons have varying velocities and also fall through a changing electric field, they also have a first Townsend coefficient a_2 which is different from the above.

For a useful counter to be obtained, it is first necessary that a_1 be large. Wilkinson (7) has demonstrated both theoretically and experimentally the effect on the Geiger counter plateau when a single electron is released by the initial ionizing event and when several electrons are released by it. In the case of the low pressure counter, a_1 is proportional to the pressure. Ramsaur (8) has shown that a_1 is also a function of the energy of the impinging electron and is an increasing quantity with increasing atomic weight of the rare gas employed. Ramsaur's work also indicates that an electron which barely passes through the window has a higher probability of being counted than one which enters the counter with an energy of 100 electron volts or more. While secondary emission from the cathode is in no physical way related to a_1 , secondary emission serves the same purpose; namely, one or two electrons are made available to fall toward the anode. McKay (9), through the work of many others, has shown that secondary emission yields may be greater than unity for primary electrons impinging on metal surfaces with energies between 150 and 1500 electron volts. The number of electrons released within the counter by a single impinging electron is a difficult quantity to determine. At best, it is a statistical quantity and is therefore subject to statistical fluctuations.

The release of one or more electrons within the counter by one or more of the above processes must be followed by additional ionization due to the collision of these electrons with other neutral atoms if a voltage pulse of sufficient size to be recorded is to be produced. This requires that a_2 be large. Loeb (10) evaluates the first Townsend coefficient for this secondary ionization process as

$$\frac{a_2}{p} = r\left(\frac{E}{p}\right), \quad (1)$$

where E is the electric field at the position of the electron considered, and p is the pressure of the counter filler. The electric field at any point between the counter anode and cathode for the

concentric cylinder electrode system is given by

$$E = \frac{V}{r/n \frac{R}{r_a}}, \quad (2)$$

where V is the voltage applied between the counter electrodes, r is the distance from the center of the counter to the point considered, R is the radius of the cathode, and r_a is the radius of the anode.

The coefficient a_2 is not a simple function. In any given gas, it is influenced greatly by traces of impurities which are difficult to control. Since Geiger counters are rarely filled with a pure gas, any tables of this coefficient obtained by experimental means are of little value. Furthermore, as indicated by equation (2), a_2 increases rapidly as the electron approaches the anode. The evaluation of the over-all probability that any single electron will initiate the train of avalanches which is detected as a pulse is, therefore, quite difficult. However, a low counting efficiency is to be expected in counters operated at the lowest pressures.

In an experimental study of the Geiger-Mueller counter, a brief examination of the characteristics of the counter voltage pulse and how it is affected by the directly connected portions of its associated electronic circuit is of some importance. For anode voltages which exceed the Geiger threshold, there is a range of anode voltages in which the Geiger pulse voltage is approximately proportional to the overvoltage. In any given counter circuit, this means that the charge collected is also proportional to the overvoltage. Examination of the anode electrode of a counter discloses that it has a very small capacitance with respect to the ground or nearby grounded conductors. It therefore follows from the relationship

$$V = \frac{Q}{C} \quad (3)$$

that any additional anode circuit capacitance resulting from the connection of the counter to any electronic system should be small if the Geiger pulse voltage is to be large, other conditions remaining fixed.

The significance of the requirement of low capacitance with respect to ground or the anode circuit lies in the fact that plateaus which are obtained from counters containing mixtures at other than the optimum pressure are expected to be shorter than plateaus obtained from counters filled to the optimum pressure. Since satis-

factory performance of a counter at a low pressure is desired, some sacrifice of the length of the plateau might be tolerated, provided that the counter can be made to perform otherwise satisfactorily as a detector of radioactivity.

The desirability of locating the electronic recording apparatus somewhat remotely from the counter, coupled with the necessity of low counter anode circuit capacitance, requires that some form of pre-amplifier be used. In this instance, the simplest form of preamplifier, the cathode follower, is also the most applicable. The cathode follower can be constructed with a very low input capacitance. At the same time, its ability to drive the capacitance of a coaxial cable is very good. It has a voltage gain factor which is less than unity, but this is not a disadvantage. For these reasons, the cathode follower is an important circuit in this investigation.

In the foregoing discussion, the difficulties of predicting exactly what should be done to prepare the desired low pressure mixture have been set forth. Because of these difficulties, the investigation about to be described was executed almost entirely by experimental procedures. The objective was the development of a Geiger counter, its associated apparatus, and the necessary techniques for detecting low energy electrons.

EXPERIMENTAL PROCEDURES

In the following sections are the experimental procedures which have been found successful in the construction and operation of Geiger counters for detecting low energy electrons.

Preparation of the Films for the Windows

One of the most important parts of this type of Geiger counter is the thin window. The windows employed in this work were prepared by either of two procedures. They are respectively designated the "glass plate-dipping technique" and the "drop of solution technique." The former procedure yielded the strongest films and was also the one most easily performed. However, the low energy limit of electron transmission was higher than with the more delicate films prepared by the latter method.

The glass plate-dipping technique

In this process, a two percent solution by weight of formvar 15/95 E in ethylene chloride was first prepared. A clean plate of glass, measuring four to five inches on a side, was submerged in this solution and allowed to be thoroughly wetted by it. This required

less than a minute, after which the glass plate was removed from the solution and allowed to dry about five minutes while standing on one edge. The plate was then dipped in the same solution again and allowed to dry for a second time.

Within a few minutes after the ethylene chloride had evaporated and the glass plate had dried, the glass plate was placed under distilled water with a film side up in a shallow dish. Along each edge of the plate, the film was torn loose with tweezers. Care was taken to prevent any tearing from proceeding into the useful central area of the film. One corner of the film was then pulled free and, by raising the glass plate, caused to float on the surface of the water. The film may be completely removed from the glass by blowing on the surfaced portion of the film and on the surface of the water. Occasional aid with the tweezers may be necessary. Properly performed, this will invert the film as it is moved from the glass to the surface of the water. However, under some conditions the film separated itself from the glass so easily that the inversion of the film was unnecessary.

The film was removed from the surface of the water with care. This was accomplished by dropping light aluminum rings (Fig. 1-g) painted with glyptal enamel on the film. After the glyptal enamel had dried for perhaps an hour, the film, supported by the rings, was removed from the water and allowed to dry thoroughly. After the films had dried, they were ready for mounting in the window frames.

These films possessed a surface density of approximately 0.3 mg/cm^2 , according to data obtained with a microbalance. Mounted in window frames (Fig. 1-j), they could be made vacuum tight while sustaining a pressure of 10 cm Hg on an unsupported area $3/8$ inch in diameter.

The drop of solution technique

In this procedure, developed originally by Backus (11) and extended by Curtis (12), each of several films was prepared by dropping five or six drops of a 0.2 percent solution of formvar E in ethylene chloride on distilled water which was maintained at a temperature of 4°C by means of an ice bath. The drops were released in rapid succession so that each of the succeeding drops struck the water before the previous drop had time to spread out completely and dry. This resulted in a uniform film which was easy to remove from the water. The films were removed from the surface of the water by approaching the film from underneath with an aluminum ring and lifting the ring out of the water at a steep angle so as

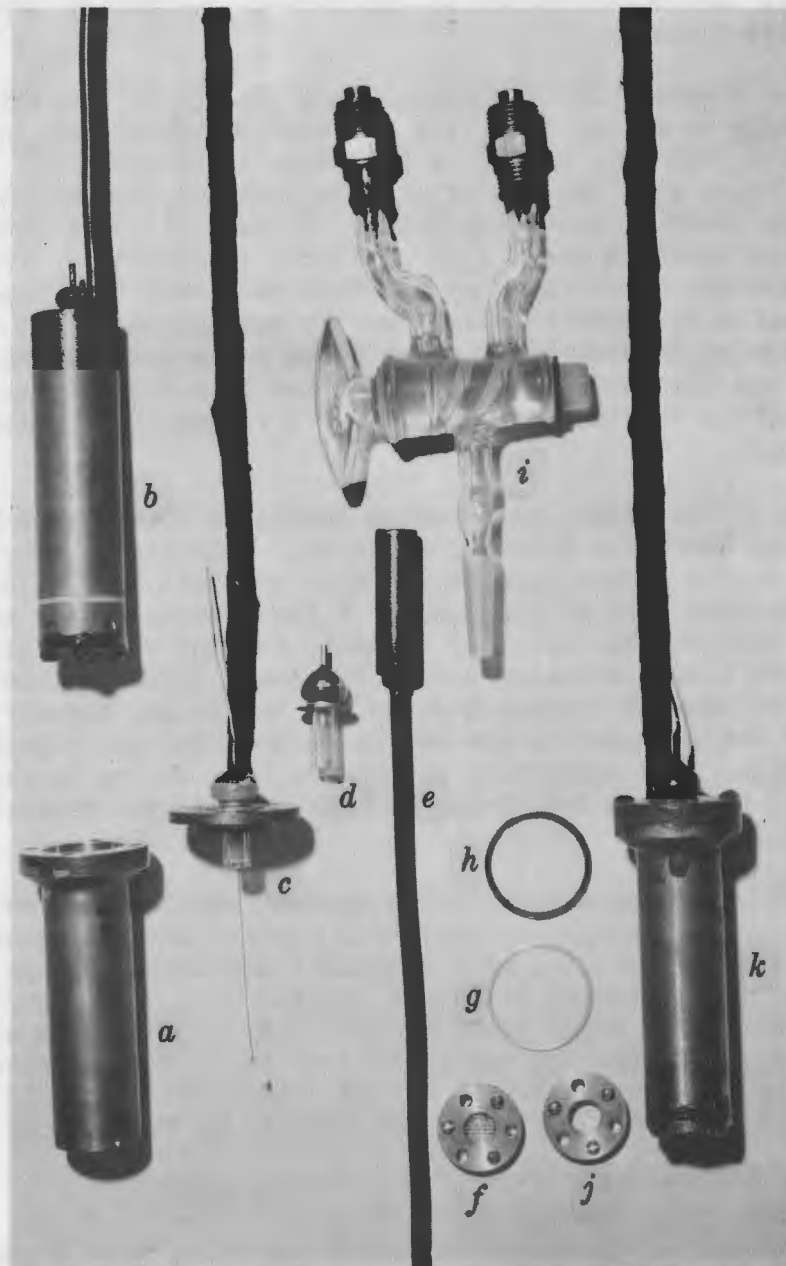


Fig. 1--The counters and the component parts: (a) copper cathode, (b) obsolete forerunner to the model adopted, (c) base assembly with anode wire unmounted ready for sealing to copper cathode, (d) unmounted kovar glass-to-metal seal, Stupakoff Type GD, No. 95.2061, (e) filling tube and brass taper, (f) drilled grid-window frame, (g) aluminum ring for supporting film window material, (h) aluminum ring with film in place, film almost invisible, (i) stop-cock, (j) open window frame, (k) completed counter.

to prevent the forces caused by the surface tension of the water from tearing the film.

Films prepared in this manner were considered too thin to be used individually as window materials for counters developed in this investigation, but this has since been done by Langer (13). Examination of these films with the aid of the electron microscope disclosed that there were about 80 holes per $6.3(10)^{-6}$ square inch of examined area. These holes averaged about $6.3(10)^{-6}$ inch in diameter. From these data it was estimated that any one film had about 0.05 percent of its area occupied by these small holes. It was believed that a laminated window made up of several of these films would possess the required strength and also be relatively effective in retaining the counter mixture within the counter in spite of a vacuum on the other side of the window.

Five of the films, prepared as described above, were assembled to form one laminated piece of material. This was done by placing one film over a second film at an angle of about 20° , allowing contact to be made only at one point. A fine stream of air was gently directed against this point of contact, forcing the two films together over a more extended area. By always directing the air stream against the line of contact between the two films, the air between the films was excluded as the two films were brought together. After the two films were completely in contact, one of the two aluminum supporting rings was cut loose, and the process was repeated on the next three films.

By extensive work correlating optical path length, as measured by the Michelson interferometer, with surface density measurements, as determined by weighing each film on a microbalance, the stack of five films was estimated to have a surface density of 0.027 mg/cm^2 . The film stack was found to be satisfactory as a counter window, but not vacuum tight. It was capable of sustaining a pressure of 2 cm Hg when mounted in a grid window frame (see Fig. 1-f) consisting of a pattern of 48 40-mil holes drilled in an area $3/8$ inch in diameter.

Mounting the films for use in counters

Regardless of the manner in which the films were prepared, they were mounted in window frames which could be sealed to one of the counters to be put in the spectrometer. Mica windows were mounted similarly. The use of window frames permitted the windows to be prepared in groups ready for mounting on the counters. In addition, a window could be removed from an old counter and placed on a new one when necessary.

The counter window frame consisted of two parts, both of brass. One piece of the frame was drilled and tapped to accept three 2-56 screws. The other piece was drilled to pass the three screws thus permitting the two parts of the window frame to be held together, clamping the film between them as shown in the photograph, Fig. 1-f, 1-j, 1-k, and in the drawing, Fig. 2.

The piece threaded to receive the 2-56 screws was painted lightly and evenly with glyptal enamel. Onto this fresh coating of glyptal enamel, the film, supported by the aluminum ring, was dropped. The other piece of the window frame was painted similarly and placed over the first piece, and the two pieces were then fastened together by means of the machine screws. Care was taken not to have an excess of glyptal enamel on either of the pieces as this excess could spoil the film window when the two pieces were clamped together. On the other hand, a deficiency of glyptal was avoided so that vacuum tight window seals might be obtained.

Other details in the technique of preparing the windows included making sure that the parts of the window frames were smooth and free from burrs and scratches. When windows were rebuilt, care was taken to assure that the meeting faces were the same as those used above. In other words, the piece which the heads of the machine screws rested against was always painted on the same side time after time. This was done so that any slight damage due to the machine screws was of no significance in the vacuum seals of later counter windows, since they were always on the outside.

Construction of the Counters

The metal parts of the counters were fabricated from standard stocks of copper and brass. Figure 2 shows the important constructional features of the counter. A photograph of each of the parts is given in Fig. 1. A counter consisting of fewer parts, but which was more difficult to assemble or to repair is shown in Fig. 1-b. Developmental work with this model was discontinued. Throughout the assembly of the counter pictured in Fig. 1-k, greater control of each step was possible.

Of all the dimensions of the interior of the counter, only two were found significant for the purpose of obtaining counters with identical characteristics. These were the length of the kovar glass sleeve protruding from the brass base and the length of the exposed tungsten wire of the anode. The kovar glass sleeve of the kovar glass-to-metal seal (Fig. 1-d) was ground so that 1.2 cm protruded perpendicularly to the brass base. After grinding the kovar glass sleeve to the proper dimensions, the glass-to-metal seal was soft-soldered to the brass base (Fig. 1-c) and then the end of the glass

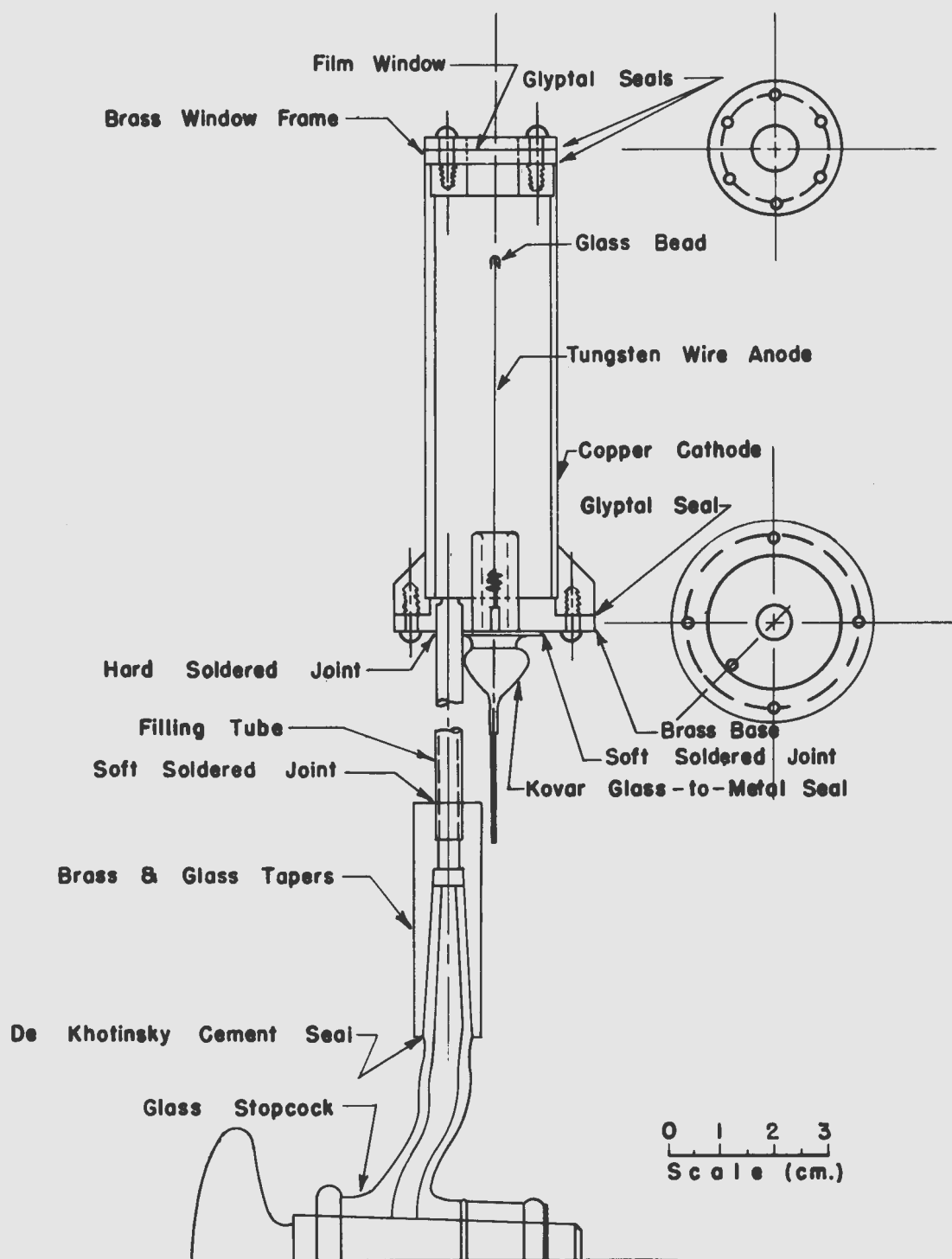


Fig. 2--Assembly drawing of the complete Geiger-Mueller counter.

sleeve was fire-polished to smoothness. After mounting the kovar seal to the brass base, the anode wire was mounted.

Before mounting the anode wire on the base assembly, it was specially prepared. The wire, which was of tungsten and 10 mils in diameter, was first prepared by polishing it with a piece of crocus cloth for perhaps an hour. This procedure removed the major nonuniformities found on the commercial grade of tungsten wire used. After the polishing process was completed, a piece of this specially prepared tungsten wire slightly longer than needed in the finished anode was crimped to a piece of No. 18 bare copper wire. Following the crimping process, the tungsten wire was straightened so that when the copper wire was inserted into the hole of the kovar seal, the wire was axially located within the assembled counter. Special care was taken to assure the axial position of the anode wire. Only after the wire was centered and the crimped portion was within the glass sleeve at least one-fourth inch was the copper wire soldered to the kovar metal tube. The soldering operation was carefully performed so as to assure a vacuum tight seal.

After the anode wire assembly was soldered in place, the tungsten wire was cut so that 5.2 cm of the tungsten were exposed beyond the end of the kovar glass sleeve. Then a small glass bead 1.5 mm in diameter and perhaps 2 to 2.5 mm in length was fastened to the unsupported end. The bead was prepared by drawing out a thick walled soft glass tube of perhaps 9 mm outside diameter so that the inner diameter of the tube was slightly greater than 10 mils after the drawing process. This made a capillary tube of the proper outside diameter. A piece of this capillary tube about 2.5 mm in length was cut off and placed on the end of the anode wire so that about one-half its length was overhanging the end of the wire. A natural gas-oxygen flame applied very gently to the end of the capillary tube closed the end of the tube down over the tungsten wire thus forming a smooth, firm junction of the glass and tungsten. Careful rotation of the anode and base assembly was necessary to produce the desired results.

The copper cathode was prepared for assembly by polishing the interior to a mirror finish. This was done by rotating the cathode at high speed while holding a moistened cloth with polishing compound or a crocus cloth against the interior surface. Final cleaning of the cathode consisted of filling the interior with a weak solution of nitric acid, followed by an extensive rinsing with distilled water, and finally by washing with ethyl alcohol. The cathode was then allowed to dry.

After the cathode had dried, it was ready for assembly to the

base. The final preparation of the anode wire consisted of immersing the entire exposed length in concentrated nitric acid for several minutes. This removed any residual grease or lint from its surface without damaging the tungsten. This was followed by a very thorough washing in distilled water; then it was allowed to dry. Care was taken following all of the cleaning operations to assure that no lint or dust particles collected on the anode assembly or the interior of the cathode.

The mounting of the base and window assemblies on the cathode were similar operations. Both of these joints required vacuum tight seals. These seals were made by painting both of the meeting surfaces at each end of the counter with glyptal enamel. The assembly was completed by fastening the parts together with seven 6-32 machine screws.

The stopcock was mounted in its brass taper (Fig. 1-c) by means of De Khotisky cement. Care was taken to assure a vacuum tight seal. The moving parts of the stopcock were greased with Apiezon grease N. As a final step in the closing of all possible leaks in the counter, all hard and soft soldered joints were painted with moderate amounts of glyptal enamel, and all joints which had been previously sealed with glyptal were retouched at the edges. In addition, glyptal enamel was painted liberally around each machine screw head. The proper drying time for all the glyptal seals was found to be about thirty-six hours.

Filling, Testing, and Storing of the Counters

Dependable performance of the counters in the spectrometer was guaranteed by testing all counters following completion of assembly. Counters with mica windows of surface densities exceeding 1 mg/cm^2 could be filled and tested without the use of a vacuum chamber. However, the counters possessing thin film windows with surface densities of 0.3 mg/cm^2 and less required the use of a vacuum chamber in the evacuation, filling, and testing operations in order to prevent the atmospheric pressure from destroying the thin window.

The vacuum chamber system

The vacuum chamber system, pictured with a portion of the portable vacuum system in Fig. 3, consisted of a glass tube four feet in length and four inches in diameter closed at the upper end. The lower end of the glass tube was sealed with De Khotinsky cement to a brass flange one-half inch thick and 6.3 inches in diameter. This flange was drilled to pass six thumb screws, which were used to clamp

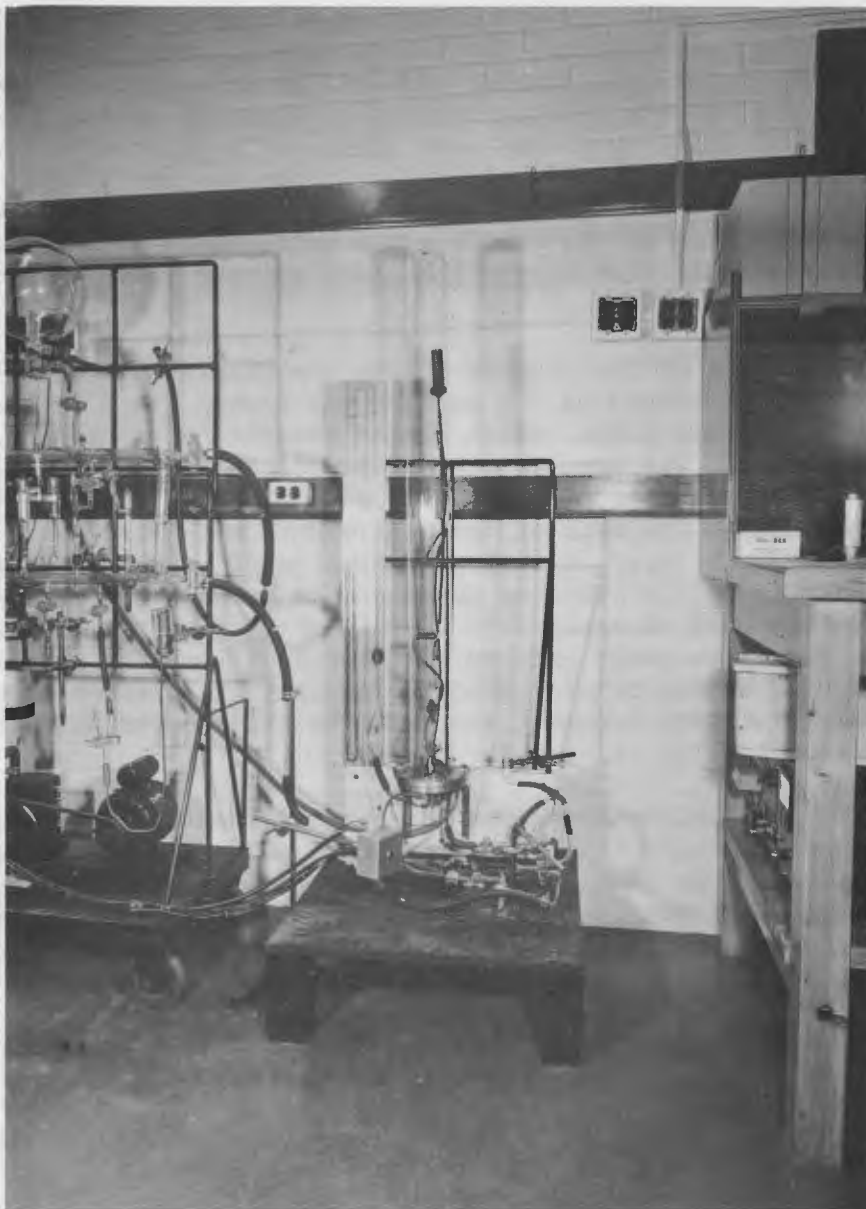


Fig. 3--The vacuum chamber system.

the vacuum chamber tube to the base plate, which was drilled and tapped to receive the six thumb screws.

All tubing and electrical connections entered the vacuum chamber through the brass base plate. The two electrical connections, which were provided, entered the chamber through two kovar glass-to-metal seals. A pair of concentrically located rectangular gasket grooves were machined in the base plate, into which neoprene gaskets greased with "Cello-Seal" were placed. An exhaust tube was provided for the pumping of the small air space between the two gaskets. This permitted the exhausting of the air from the main chamber and counter in spite of any small leak which might have existed in the first gasket.

The connection of the counter within the chamber to the tubing and controlling stopcocks on the outside was accomplished by means of tapers in the base plate, which fitted standard glass tapers. De Khotinsky cement was used to make these joints vacuum tight. The socket of the ball and socket joint completed the upper part of the base assembly. The ball of the ball and socket joint, which was fitted with a glass taper, could be removed readily from the base assembly, sealed to the stopcock taper on the Geiger counter, and replaced on the base assembly with a minimum of trouble. The ball and socket joint, properly greased with Apiezon grease N, permitted the positioning of the counter prior to placing the chamber tube on the base plate without breaking the seals to the counter and without danger of damaging the glass parts.

A pair of tubes connected the chamber and counter feed tubes to a differential pressure manometer. A second pair of tubes connected these same feed tubes to a pair of isolating stopcocks which, in turn, were joined to a common line controlled by a master stopcock. From the latter control, a single line extended to the portable vacuum system.

The procedure followed in the testing of counters with the aid of this apparatus consisted of the following operations:

1. The simultaneous pumping of the air from the counter and from the chamber so that the pressure sustained by the window was very small.
2. The maintenance of the pressure on the window at a low level while pumping the interior of the counter to a high vacuum (about one micron Hg).
3. The admission of argon to the counter at the pressure at which the window was to be tested, followed by continuous pumping of the vacuum chamber to check for leaks. If a

leak did not manifest itself by a slight decrease in pressure on the differential manometer in a 24 hour pumping period, no leaks were present.

4. The evacuation of the argon followed by the simultaneous admission of an inexpensive counter mixture at the proper pressure to the interior of the counter with the admission of air to the vacuum chamber in a manner such that the counter pressure only slightly exceeded the chamber pressure. The admission of air to the chamber was necessary in order to prevent spurious spark discharges from occurring between the electrical connections outside the counter.
5. The checking of the plateau characteristic and background of the counter while it was in the chamber.
6. The simultaneous admission of argon to the counter and air to the chamber to raise the internal pressure of the counter to atmospheric pressure, keeping the pressure sustained by the window very small.

The counters with the 0.3 mg/cm^2 windows were usually removed from the vacuum chamber with their internal pressures about 3 cm Hg above atmospheric pressure. In this condition, a counter could be stored until needed. The counter with the 0.027 mg/cm^2 window was stored with argon inside at atmospheric pressure, but the stopcock at the end of its filling tube was not turned so as to seal the counter from the atmosphere. Instead the counter was allowed to breathe in accordance with the atmospheric pressure changes which were brought about by weather and room temperature variations.

These procedures permitted the thin window counters to be handled in very much the same manner as counters with more durable windows. When inserted in the beta-ray spectrometer, they could be evacuated and filled in much the same manner as described in the above list of operations. The procedure of storing the counters with argon within them was not as important as keeping their interiors free from corrosion and dirt; however, the "argon-storage" method was foolproof and was used whenever the strength of the window permitted.

The portable vacuum system

The portable vacuum system shown in Fig. 4 was originally constructed for two purposes: the filling of mica window counters prior to their installation in the spectrometer and the refilling of a counter already installed. As the work progressed and the need for the vacuum chamber arose, the portable system was modified so that it could be used in conjunction with the vacuum chamber.

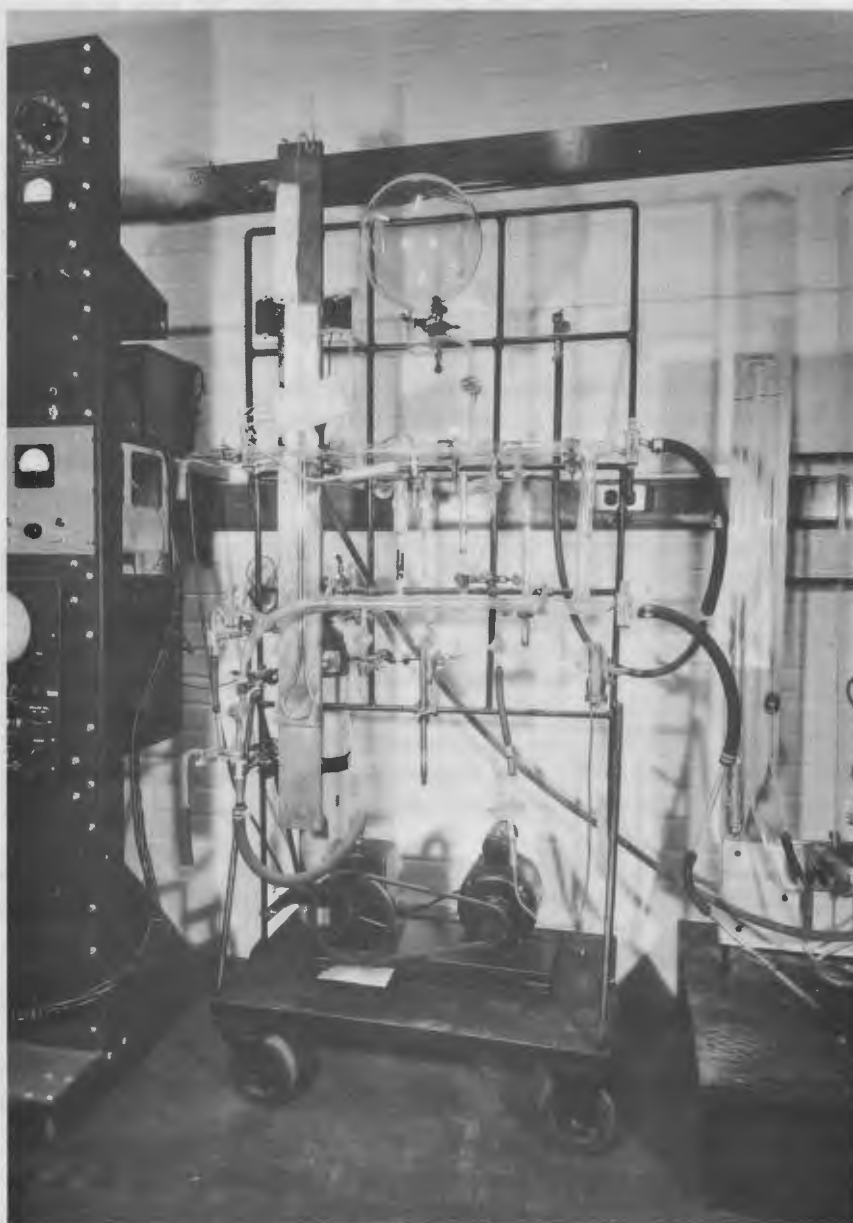


Fig. 4--The portable vacuum system.

Complete facilities were provided for measuring pressures with the pirani gauge, McLeod gauge, and the mercurial manometer. Storage flasks, for mixtures prepared in advance, were also provided. Hose connections and glass tapers were provided so that the system could readily be connected to the vacuum chamber, the counter in the spectrometer, or to other auxiliary apparatus. The mechanical pump was a Cenco-Hyvac pump manufactured by the Central Scientific Company.

The mixture research vacuum system

The mixture research vacuum system, Fig. 5, was a collection of apparatus used for preparing various gas and vapor mixtures for study of their properties in Geiger counters. Facilities for preparing standard counter fillings were provided initially; however, provision for introducing additional gases and vapors as the need arose was included. Since the photograph was made, additional flasks for mixtures have been added. The pumping equipment included a Duo-Seal vacuum pump manufactured by the W. M. Welch Scientific Company and an air-cooled, single stage, glass diffusion pump, type G-4, manufactured by the Distillation Products Company. The current to the diffusion pump heater coil was controlled by means of a variac and set to the proper value indicated on an ammeter (top panel, Fig. 9).

The vacuum gauging equipment for the mixture research system included a large mercurial manometer for the pressure range 0 to 90 cm Hg and a small mercurial manometer for the pressure range 0 to 10 cm Hg. In order to prevent the vapor pressure of the mercury from influencing the ultimate degree of vacuum possible with the diffusion pump, the high range manometer was connected to the vacuum line by means of a two-position stopcock. The small manometer, which was permanently in the vacuum line, had about one centimeter of Octoil-S diffusion pump oil on the top of the mercury column to eliminate the mercury vapor pressure from this source. The pirani gauge was connected to the vacuum line by way of the same stopcock as the large manometer. The stopcock was provided so that the large range mercurial manometer and the pirani gauge tube could be disconnected from the vacuum line, thus reducing the total volume of the system to a value as small as possible.

The reason for the small volume in the main portion of the vacuum system was that Geiger counter mixtures using expensive rare gases were contemplated. Under most circumstances in experimental work, any residual gas in the system itself is lost.

The ion gauge tube was sealed to the high vacuum side of the diffusion pump. The diffusion pump was connected to the system and mechanical pump by way of two stopcocks which made possible the isola-

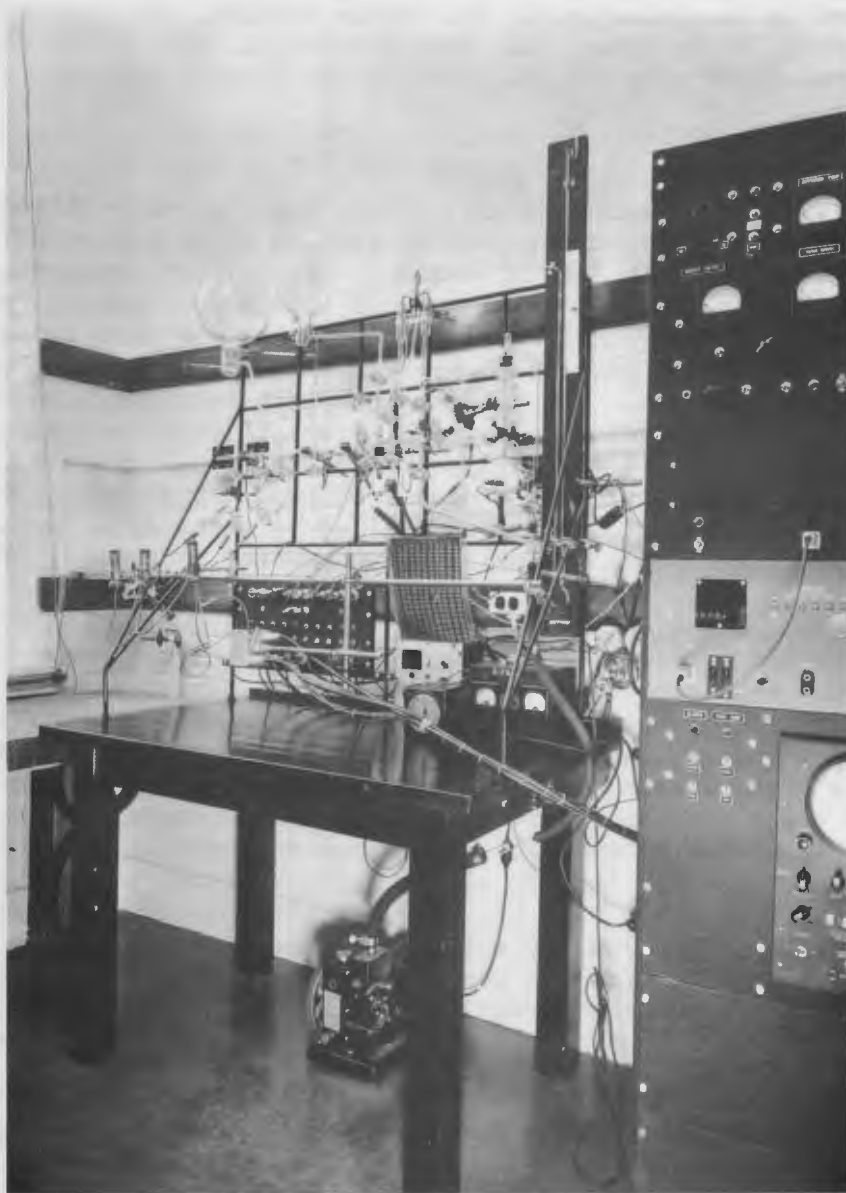


Fig. 5--The mixture research vacuum system.

tion of the diffusion pump and the ion gauge tube so that the mechanical pump could be connected to the main vacuum system for exhausting any gas at higher pressures without the need of turning off the ion gauge tube or of cooling the diffusion pump.

The ion gauge tube was an Eimac type 35-T tubulated for easy joining to the vacuum system. Electrically, it was connected to an ion gauge circuit (the panel with three meters, Fig. 9) designed at Berkeley. This circuit contained an emission current regulator and provided pressure ranges from 0 to 10 millimicrons for the lowest range and from 0 to 2 microns for the highest range. Intermediate pressure ranges were also provided. A circuit which was sensitive to excessive pressure on the high vacuum side, by way of the ion gauge tube, furnished means for automatically turning off the ion gauge and pumping equipment in the event of a serious leak.

A vacuum manifold for pumping and filling several counters simultaneously was included. It was connected permanently to the vacuum system through a stopcock which permitted the isolation of the manifold from the small-volume portion of the vacuum system. On the left side of the table near the back, a steel panel equipped with numerous electrical connections furnished a switching system for changing the Pirani gauge meter box from the Pirani gauge tube on the research system to the Pirani gauge tube on the portable vacuum system. Leak detection circuits could also be switched to either system from this panel.

Procedures of the mixture studies

Good counters which operated at a low pressure were the objective of the work with the research vacuum system. To conduct this study, two counters of the same type as those used in the beta-ray spectrometer were constructed. They were made as nearly alike as possible. On each of the counters a mica window, sufficiently thick to withstand the atmospheric pressure, was mounted. Initially, both the counters were sealed into the vacuum manifold, and any experimental mixtures tested in one counter were also tested in the other. Proof that the data were reliable was established by the fact that similar performance was obtained from both counters.

Data recorded in each of the tests included the anode voltage of the counter, the total count, the elapsed time for the count, and the size of the Geiger pulse as measured on a synchroscope. From these data, the counting rate as a function of the anode potential and pulse height could be obtained. Plateau curves were plotted for each mixture tested.

The mixtures tested included argon and ethyl alcohol, argon and

ethylene, and krypton and ethyl alcohol. The first mixture tested in these two counters consisted of 10 percent ethyl alcohol and 90 percent argon at a total pressure of 10 cm. The data obtained from the counters using this mixture served as a standard to which all other Geiger counter data obtained from these counters using other mixtures was compared. To facilitate comparison of data obtained from one counter mixture with data obtained from another counter mixture, a piece of uranium was mounted in a brass holder which was machined so as to fit over the Geiger counter window in exactly the same position each time it was used. The condition of the anode and cathode electrodes was periodically checked by admitting the standard 10 percent ethyl alcohol and 90 percent argon mixture and then taking plateau data. This procedure disclosed that there was no deterioration of the counter electrodes throughout the progress of the work.

Subsequent mixture studies were carried out on the hypothesis that when the total pressure of the mixture was reduced, the amount of quenching agent in the counter should be maintained at a partial pressure of approximately one centimeter. This meant that the amount of the quenching agent expressed as a percentage of the total pressure was increased. In the experimental work, it was found convenient to fill the counter with one of the mixtures to be tested to the maximum pressure of interest, take data on the performance of this mixture, reduce the pressure in the counter by 1-2 cm Hg, and then take data on the counter performance again. The procedure of reducing the pressure, followed by the taking of data, could usually be repeated several times before the counter pressure became so low that its performance was unsatisfactory.

After the plateau curves of each mixture were obtained, they were compared with those obtained previously. From this comparison, a new ratio of quenching agent in the vehicular gas differing by a small step from the preceding one was established, and another set of plateau curves was obtained for another series of progressively reduced pressures. The mixtures were studied in the pressure range from 10 cm Hg down to 0.8 cm Hg. The ethyl alcohol concentration was varied from 10 to 40 percent in the vehicular gases argon and krypton. Only the krypton was of spectroscopic grade. Ethylene was also tested as a quenching agent.

The Geiger Counter In Use

Once a Geiger counter has been made, it must be connected to proper electronic equipment which, in turn, must be operated carefully if acceptable performance and reliable data are to be obtained. The following two sections describe the electronic apparatus and the manner in which it was operated to achieve the desired results.

Electronic equipment

The complete electronic system employed in the Geiger counter developmental work and in the use of the counters in the beta-ray spectrometer consisted of the cathode follower, which was connected by short leads to the counter, a coupling amplifier, synchroscope, and scaling circuit. These units are illustrated in block diagram form in Fig. 6 and are also shown in the photograph, Fig. 9. This system enabled a count to be recorded on the scaling circuit and register while it was viewed at the same time on the screen of the synchroscope.

The cathode follower, diagrammed in Fig. 7, was found to be very satisfactory in Geiger counter work. It is the small aluminum box, pictured near the base plate of the vacuum chamber (Fig. 3), on the table near one of the counters in Fig. 5, and just to the right of the synchroscope in Fig. 9. The parts used in this unit were as follows:

C 0.0001 mfd. 2500 volt mica capacitor

R_Q 1 megohm $\frac{1}{2}$ watt resistor

R_G 220 K $\frac{1}{2}$ watt resistor

R_C 62 ohms $\frac{1}{2}$ watt resistor

R_K¹ 3.3 K 2 watt resistor

Tube 6J4.

Two components not shown in the figure include an 8 mfd. 450 volt electrolytic capacitor from +B to ground and one 0.01 mfd. 2500 volt mica capacitor from +HV to ground.

This cathode follower unit had a voltage amplification of 0.96, an input capacitance of 4.2 micromicrofarads, and an output impedance of 75.3 ohms, all calculated values. By measurement, the voltage amplification was found to be 0.95. Counter performance was satisfactory on all lengths of cable tested, including a 60-foot length. Details observed in the construction of this unit included such features as the very minimum lead length between the counter and unit and a chassis layout permitting the minimum amount of metal in the grid circuit of the 6J4.

The heater and plate circuit power requirements of the cathode follower were supplied by the power supply shown schematically in

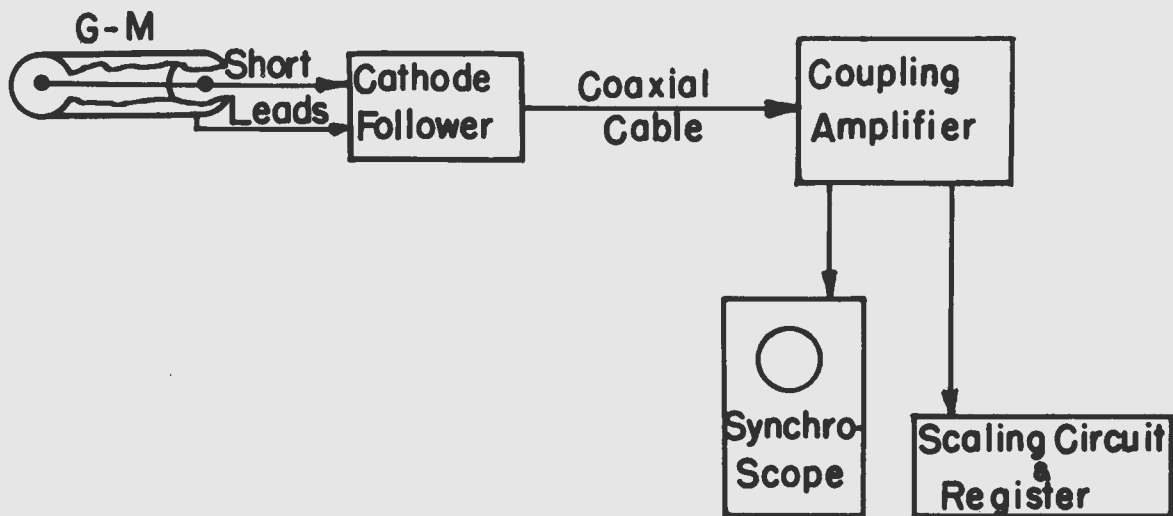


Fig. 6--Block diagram of the counter, cathode follower, coupling amplifier, synchroscope, and scaling circuit.

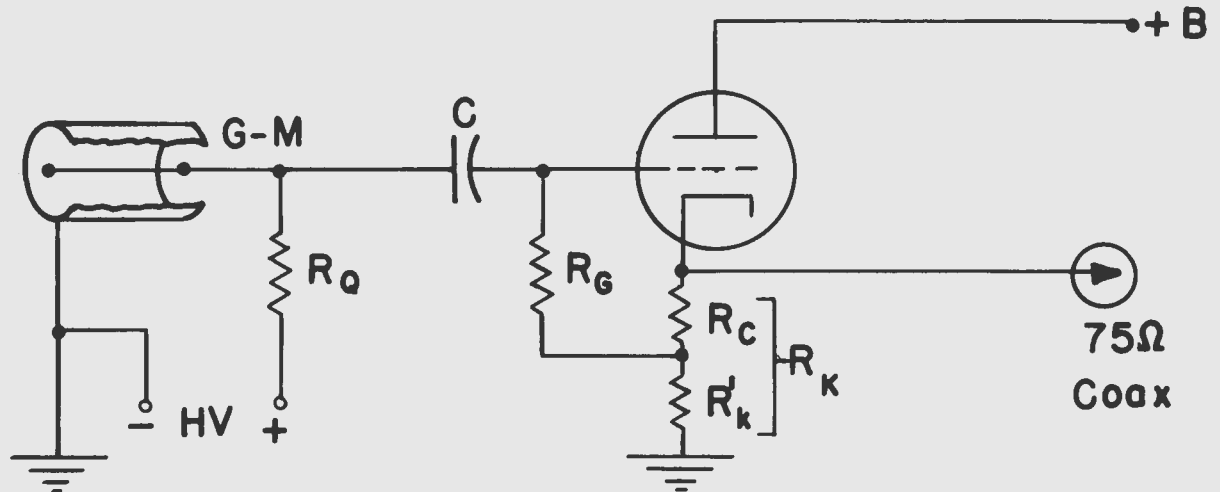


Fig. 7--The cathode follower circuit for Geiger counter work.

Fig. 8. In addition, this unit furnished the necessary power to the coupling amplifier also shown in Fig. 8. The coupling amplifier circuit was wired with appropriate connectors so that the signal from the cathode follower could be sent to the scaling circuit input for recording, and also amplified to an appropriate amplitude prior to sending the signal to the synchroscope for viewing.

The scaling circuit, model 165, was a standard scale-of-64 unit manufactured by the Nuclear Instrument and Chemical Corporation. The synchroscope was a type P4-E manufactured by the Browning Laboratories, Incorporated. The synchroscope was modified in a manner which made it especially suitable for viewing the randomly occurring pulses from the Geiger counter. This modification has been adequately described by Leachman and Palmer (14).

Operation of the counter and its equipment

To successfully operate a Geiger counter which is filled with a low pressure mixture, it is necessary that care be taken or poor results will be obtained. The first step in operating any of the counters in the spectrometer consisted of taking a complete set of plateau curve data, including the applied anode voltage, the height of the Geiger pulse at each voltage setting, and the counting rate. The counting rate was plotted as a function of the anode voltage, placing alongside each plotted point the pulse height that occurred at each of these anode voltages.

The anode voltage and pulse height at which the counter was operated was selected on the basis of the points on the plateau. However, instead of operating the counter in the middle of the plateau or necessarily on the flattest part, it was always operated at a point near the low voltage end of the plateau, a little above the knee of the curve. A pulse height, once selected, was maintained throughout the taking of data with the counter. This means that under varying operating conditions, any changes in threshold voltage which resulted were compensated for by readjustment of the counter anode potential so that the pulse height was kept at the chosen value, rather than operating the counter at a fixed potential, as is sometimes the practice.

The importance of this mode of operation is more fully realized when it is noted that a change in counter temperature of 1°C can, in some instances, change the threshold voltage by 10 volts. When the counter has a short plateau with a slope exceeding 10 percent per hundred volts, a few degrees change in room temperature can lead to the destruction of the counter because of excessive overvoltage. On the otherhand, a reversal of this type of change can cause the counter to cease to operate, unless the anode voltage is readjusted

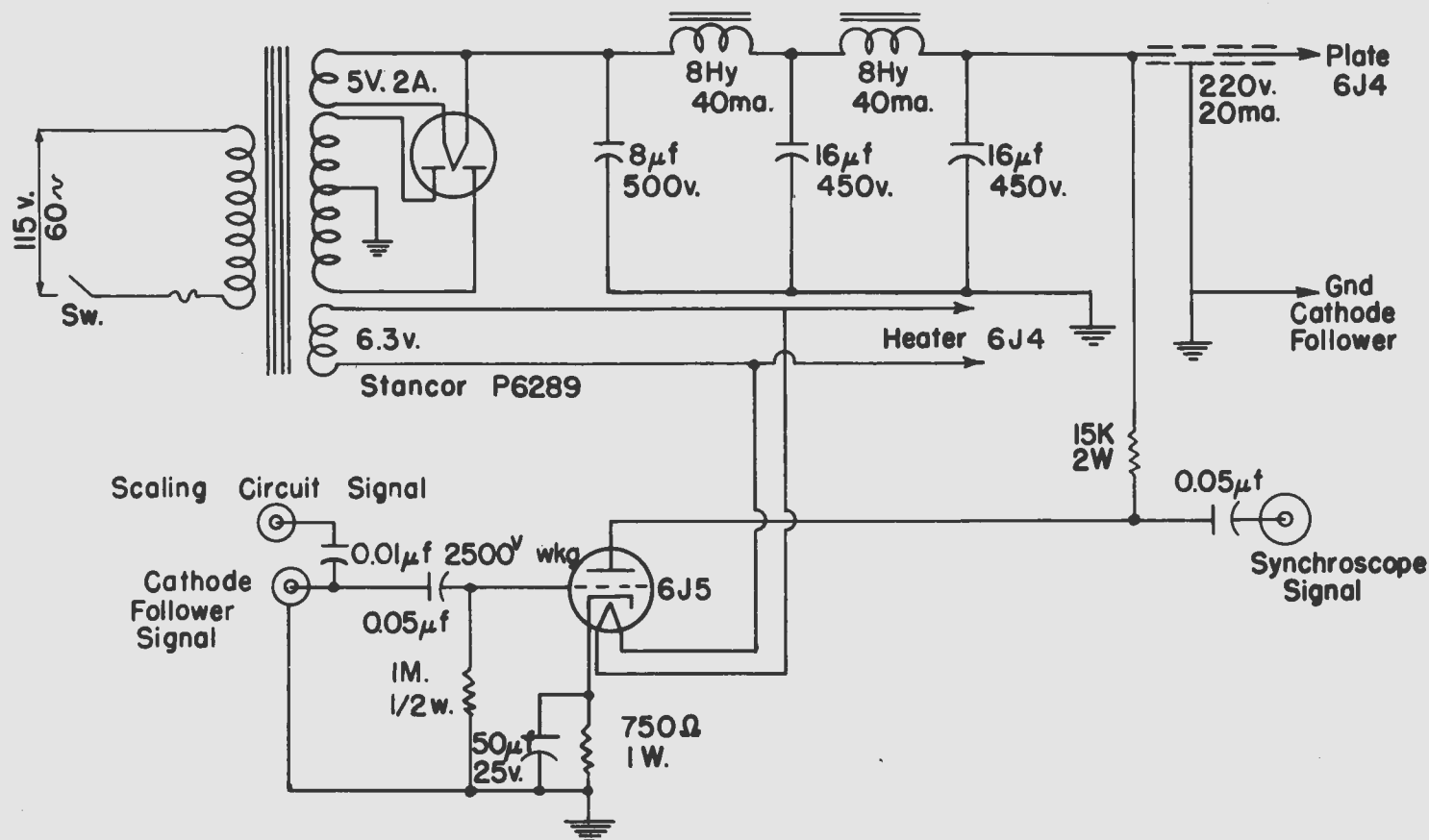


Fig. 8--Circuit diagram of the coupling amplifier and the power supply for the cathode follower and coupling amplifier.

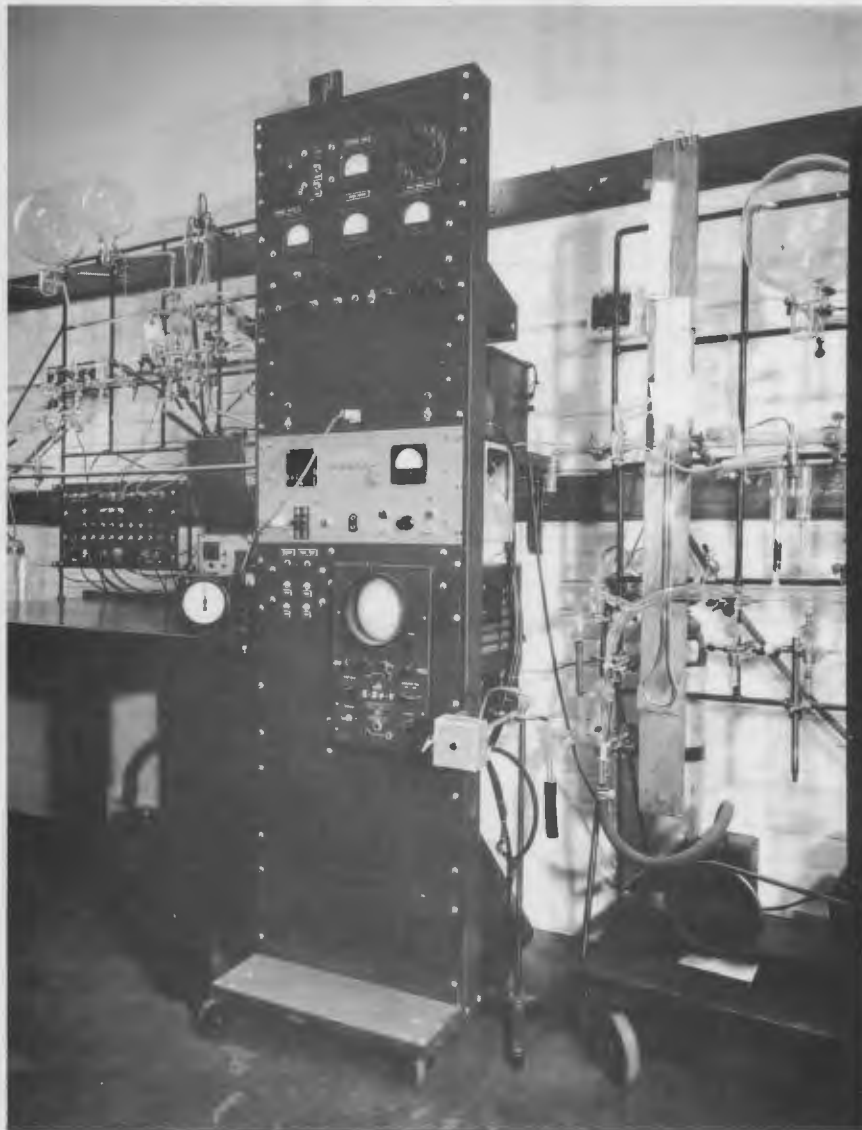


Fig. 9--Rack of electronic equipment: top panel, diffusion pump heater current control and meter; second panel, ion gauge circuit; third panel, coupling amplifier; fourth panel, scaling circuit; fifth panel, synchroscope; to the right of the synchroscope, cathode follower circuit clamped on ring stand; and on the table to the left of the rack, electric time clock.

so as to maintain a constant pulse height. This same mode of operation can also compensate for small changes in mixture pressure due to a slow leak in the counter window and for changes of threshold voltage attributed to counter aging. An additional advantage in this procedure was found in the fact that the size of the pulse from the counter was very sensitive to changes in the overvoltage.

RESULTS AND CONCLUSIONS

In the preceding pages, pieces of apparatus have been described which were designed for a specific purpose. Techniques were set forth which, when properly executed, have been found to yield useful counters for research in beta-ray spectroscopy. Figure 10 shows a group of Geiger counter plateau curves which were obtained during the course of this work.

Curve P_1 shows a typical plateau characteristic for the standard mixture in Geiger counter work, namely 10 percent ethyl alcohol and 90 percent argon at a total pressure of 10 cm Hg (mixtures No. 1). Many other plateau curves were obtained from the test counters using various pressures of counter mixtures and various percentages of ethyl alcohol from 10 percent to 33 percent concentration. Of all of these trials, mixture No. 2, consisting of 33 percent ethyl alcohol and 67 percent argon, proved to be the best for the argon-alcohol combination at the low pressure of 1.4 cm Hg. Curve P_2 shows the plateau to be short, but possibly of some use if care is taken.

Curve P_3 shows the excellent plateau characteristic which is possible through the use of mixture No. 3, consisting of 10 percent ethylene and 90 percent argon, at a total pressure of 10 cm Hg. This mixture, established by Morganstern, et al. (15), was found to be very satisfactory when used at a pressure of 10 cm Hg. However, combinations of ethylene and argon were found to be generally not as satisfactory at the lower pressures as the 33 percent ethyl alcohol and 67 percent argon mixture.

A study of mixtures of krypton and alcohol was also made. The first mixture tried consisted of 10 percent ethyl alcohol and 90 percent krypton at a total pressure of 7.4 cm Hg. The plateau curve obtained from a counter using this mixture was found to possess a smaller slope than curve P_1 over a range of anode potentials exceeding 100 volts. In counting efficiency, this mixture was equal to the mixture which yielded curve P_1 .

Following the procedure established above, the principle of which was originally set forth by Weisz (16), the concentration of the quench-

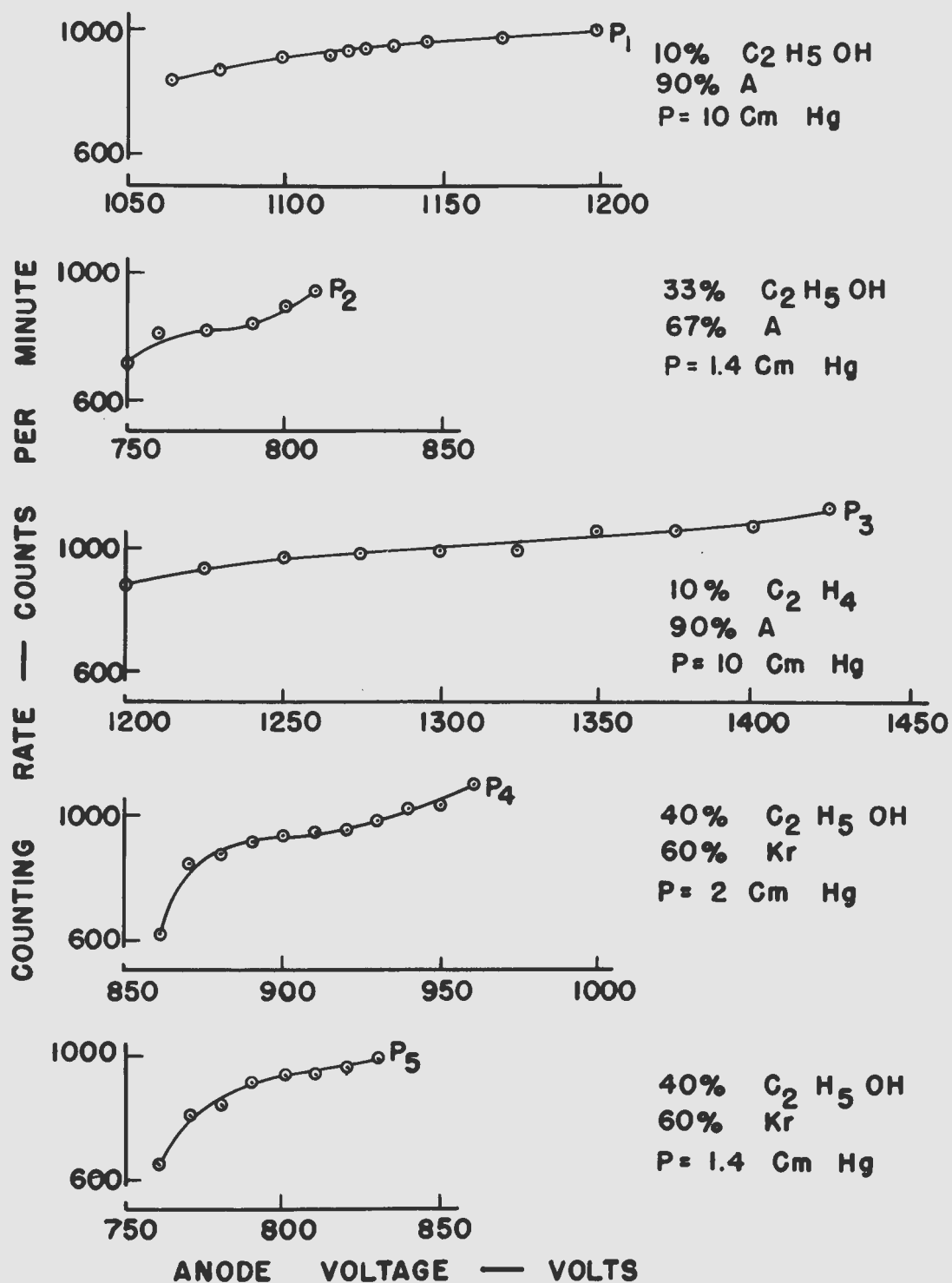


Fig. 10--Typical plateau curves of counters filled with various mixtures at several pressures.

ing agent was increased at the reduced pressures. Out of the possible mixtures that might have been tried, a mixture (No. 4) consisting of 40 percent ethyl alcohol and 60 percent krypton was selected for the low pressure studies. It was tested in the pressure range of 4.4 cm Hg down to 1.1 cm Hg. At the pressures of 4.4, 3 and 2.5 cm Hg, the plateau characteristics were practically the same as that found for the mixture consisting of 10 percent ethyl alcohol and 90 percent krypton at a pressure of 7.4 cm Hg. Curves P_4 and P_5 show the plateau characteristics obtained with this mixture in the test counter at pressures of 2 and 1.4 cm Hg respectively. At a pressure of 1.1 cm Hg, this mixture yielded a plateau curve which resembled P_2 .

Of interest in this work is the counting efficiency of a Geiger counter mixture as the pressure of the mixture is reduced. For each plateau curve, an average counting rate was established by calculating the arithmetic mean of the points on the part of the curve with the least slope. The counter filled to a pressure of 10 cm Hg with mixture No. 1 was assumed to have an efficiency of 100 percent. According to Korff (17), this is a valid assumption. Relative to these data, the efficiencies of the other mixtures were calculated. Curve E_1 in Fig. 11 shows the relative efficiency of the argon-ethyl alcohol mixtures as a function of the total pressure. The relative efficiencies of mixtures of krypton and ethyl alcohol are shown by curve E_2 . That the krypton mixture would be the more efficient of the two at the lowest pressures was qualitatively expected on the basis of Ramsaur's (8) results.

Stability of the counters was generally good. For the higher pressures, the counters were more stable than at the lower pressures. With mixture No. 2 at a pressure of 1.4 cm Hg, the data were not as closely reproducible as with mixture No. 4 was more efficient than mixture No. 2 at each corresponding low pressure. Parallel with this greater efficiency for the former two mixtures, there was a much greater stability. This is apparent in the plateau curves P_4 and P_5 as compared with curve P_2 . These results agree with the discussion given by Korff (17).

The progress which has been made in the development of a Geiger-Mueller counter for low energy electrons can best be illustrated by the curves given in Fig. 12. Here four different thicknesses of window material were employed as Geiger counter windows. Curve K_1 , obtained by Jensen (18), shows an energy cut-off for electrons at about 44 Kev, point F in the figure. These data were obtained with a counter having a mica window possessing a surface density of 3.9 mg/cm². The radioactive source used was Se^{75} which ejected photoelectrons from a 37 mg/cm² Pb radiator.

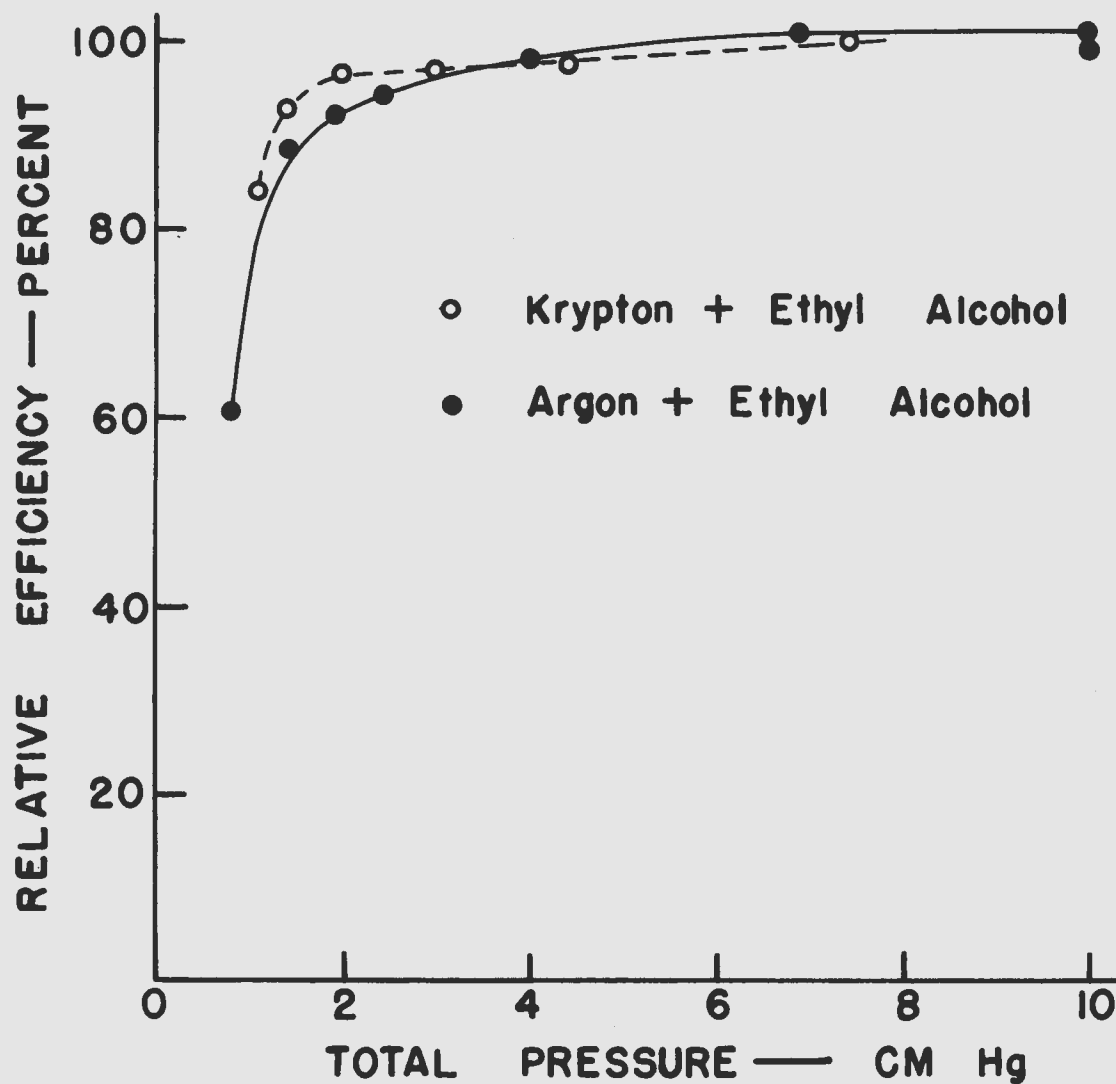


Fig. 11--Relative efficiencies of counter mixtures as function of changes of mixture pressure.

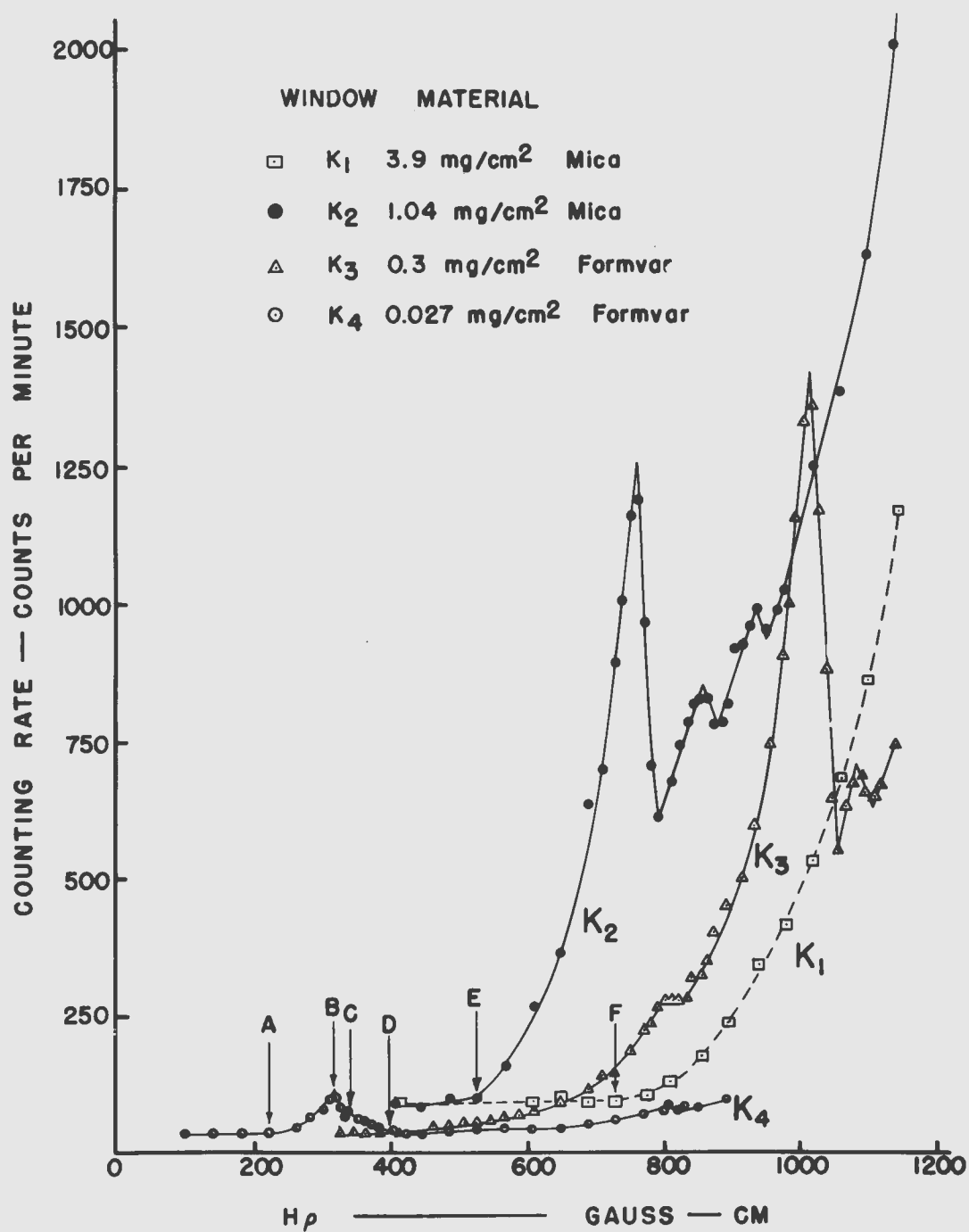


Fig. 12--Internal conversion and photoelectric spectra of Se^{75} from 200 to 1200 gauss-cm.

Curve K_2 was obtained through the use of a counter possessing a mica window with a surface density of 1.04 mg/cm^2 . The source was again Se^{75} , but the Pb radiator had a surface density of 42.3 mg/cm^2 . The energy cut-off of this window, point E, was found to be about 23.2 Kev. The difference between K_1 and K_2 should be noted; three photo-electron lines were undetected by the counter with the 3.9 mg/cm^2 window.

The results of the major effort of this investigation are found in curves K_3 and K_4 . The data represented by curve K_3 were obtained by means of a counter possessing a 0.3 mg/cm^2 window prepared from formvar. Curve K_4 was obtained with the aid of a counter possessing a 0.027 mg/cm^2 window, also of formvar. For these latter two curves, Se^{75} was again the source, but the internal conversion spectrum was examined. For the 0.3 mg/cm^2 window, the cut-off energy for electrons, at point D, was about 13.7 Kev. By means of a counter with the 0.027 mg/cm^2 window, electrons with energies down to approximately 4.3 Kev (point A) were detected.

The internal conversion lines shown at points B and C are at 9.07 and 10.31 Kev respectively. The former is the X-ray energy of As less the L-binding energy of As. The latter is the same X-ray energy less the M-binding energy. A calculation using 1.52 Kev for the L-binding energy gave an X-ray energy of 10.59 Kev, which is in good agreement with the value of 10.54 Kev given by Compton and Allison(19).

None of the data represented in Fig. 12 were corrected for decay of the sample. If curve K_4 is compared with K_3 , keeping in mind the correction for decay, it is seen that the internal conversion lines at B and C are fairly intense. Since nothing was found at these two points with the counter using the 0.3 mg/cm^2 window in spite of the higher intensity, the progress of the work in the development of a Geiger-Mueller counter for low energy electrons is quite apparent.

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APPENDIX

Sources of Special Materials

Formvar 15/95 E:	Shawinigan Products Corporation Empire State Building New York, New York
Ethylene chloride:	Paragon Testing Laboratories Orange, New Jersey
Glyptal: (1201 red enamel):	General Electric Company Schenectady, New York
Ethyl alcohol:	Vacuum Specialties 3648 North St. Louis Chicago, Illinois
Rare gases - Krypton:	The Linde Air Products Company 30 East 42nd Street New York, New York
- Argon:	The Matheson Company, Inc. P. O. Box 966 Joliet, Illinois
De Khotinsky cement: (sealing compound)	Central Scientific Company 1700 Irving Park Road Chicago, Illinois
Kovar glass-to-metal seals: (No. 95.2061 Type GD)	Stupakoff Ceramic and Mfg. Co. Latrobe, Pennsylvania
Apiezon grease N:	James G. Biddle Co. 1316 Arch Philadelphia, Pennsylvania
Cello-Seal: (vacuum gasket grease)	Fisher Scientific Company 717 Forbes Street Pittsburgh, Pennsylvania